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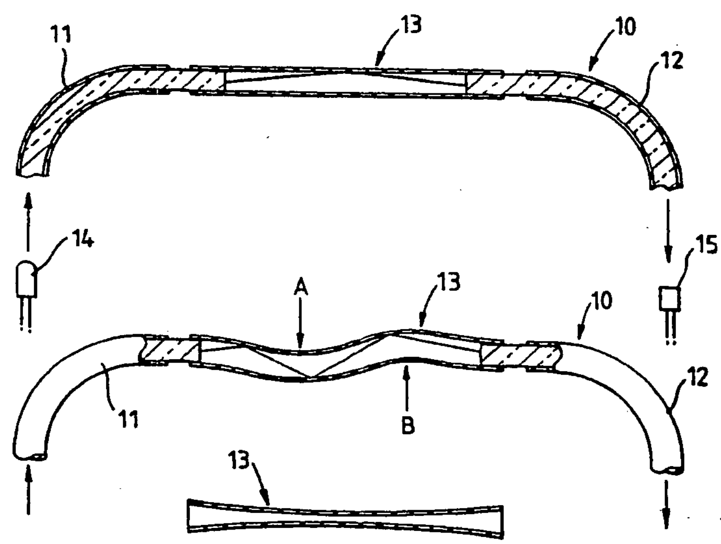

(57) Abstract

An optical displacement sensor (10) comprises a flexible tube (13) having a reflective internal surface. One end of the tube (13) is connected to a light source (14) via a solid optical fibre (11). The other end of the tube (13) is connected to a light detector (15) via another optical fiber (12). Light from source (14) passes through the tube (13) and is detected by detector (15). The tube (13) is connected to a measurand such that displacement of the mesurand causes deformation of the tube (13), and such deformation is detected by variation in the intensity of light transmitted through the tube (13). The sensor is also able to detect changes in pressure to which the tube (13) is subjected. In a modified form, both the light source and detector are located at the same end of the tube, and light passing through the tube is reflected from the other end back to the detector.

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"OPTICAL DISPLACEMENT SENSOR"

THIS INVENTION relates to an optical transducer and, more specifically, an optical displacement sensor which uses deformation or deflection of a tubular optical element to detect small displacements, typically of the order of 1 to 5 mm.

BACKGROUND ART

Optical displacement sensors or motion detectors are particularly useful in applications in which a degree of isolation, either physical or electrical, from the measurand is required. The force or work required to displace or otherwise operate an optical sensor is extremely small, thereby allowing greater accuracy and sensitivity to be achieved.

It is known to use solid optical fibres as displacement transducers. In such fibres, light is propagated through the fibre by total internal reflection due to the difference in refractive index between the fibre and its surrounding medium. In Optical Fiber Sensors: Systems and Applications, Culshaw and Dakin, Eds., Artech House, at page 438 *et. seq.*, various optical sensors are described in which the transmission of light through the fibre is affected by the bending of the fibre, primarily the loss of higher modes, i.e. the light rays which are internally reflected at angles close to the critical angle. However, such optical fibre sensors have limited application and require complex and sensitive detection equipment. For example, such sensors are typically used for detecting very small displacements of the order of microns, but are not suitable for detecting larger displacements of the order of millimetres. Further, such optical fibre sensors normally require some reliable form of intensity referencing. The need for such highly sensitive and complex equipment limits the practical uses of such optical fibre sensors.

There are other forms of optical displacement sensors or transducers, and these can be classified generally into four major groups or types. The first type

of optical displacement sensor comprises two optical fibres each having an end cut to provide an end face substantially perpendicular to the fibre axis. The fibre ends are positioned so that the faces are opposed and parallel, and closely spaced apart. When the fibre axes lie on a common straight line, light propagating in one fibre will couple with maximum intensity into the other fibre. However, when there is relative displacement of the ends of the two fibres normal to the straight line, the amount of light coupled between the fibres will be reduced. If the end of one fibre is held stationary, the displacement of the end of the other fibre can be measured by reference to the amount of light coupled between the two. An example of this type of sensor can be found in U.S. Patent No. 4,293,188.

In a second group of optical fibre displacement sensors, the end of an optical fibre is positioned in front of a reflective surface. Displacement of the reflective surface relative to the end of the fibre is measured by the amount of light reflected from the reflective surface into the optical fibre.

A third group of optical displacement sensors uses a shutter, fringe or variable aperture member connected to the measurand. Displacement of the measurand is measured by the amount of light which the shutter, fringe or aperture member allows into the optical fibre.

In a fourth type of optical displacement sensor, the strain on a photoelastic material changes the axis of polarisation, which in turn affects the amount of light transmitted through the material. This type of optical displacement sensor is particularly suitable for use in strain gauge applications.

A common disadvantage of known optical displacement sensors is the requirement of precise setup arrangements. Some sensors also require additional complex optical devices or components, such as micro lenses, polarisers, shutters or birefringent materials. Further, contamination of optical transmission surfaces with dust or

corrosive agents limits the performance of the sensors, particularly in industrial or harsh environments.

SUMMARY OF THE INVENTION

It is an object of this invention to provide an optical displacement sensor which is relatively simple to manufacture and can be installed and operated without requiring a great detail of precision, yet is reliable and offers the benefits of optical fibre instrumentation, such as noise immunity, electrical isolation, moisture and vibration tolerance, and ease of miniaturisation and manufacture.

In one broad form, the present invention provides an optical displacement sensor comprising an elongate flexible optical element suitable for the passage of light axially therethrough, the optical element being deformable by displacement of a first portion thereof relative to another portion; a light source optically coupled to one end of the optical element for transmitting light radiation into the optical element; and a light detector for detecting the light radiation after passage through the optical element, the light detector providing an output indicative of the intensity of light detected, wherein the detector output is responsive to variation in the intensity of light transmitted through the optical element as a result of deformation thereof,

characterised in that the optical element is a tubular member.

The term "light" as used in this specification and claims is intended to include not only visible light, but also infrared or ultraviolet radiation, unless stated otherwise or the context does not permit.

Typically, the tubular member is a thin polymer tube having a reflective internal surface. The surface may be mirrored, but not necessarily so. Light is transmitted through the tube by a combination of direct radiation and reflection from the internal surface.

As each reflection from the internal surface will be less than 100% efficient and as the number of

reflections will increase with the amount of deflection or bending of the tubular fibre, the intensity or amount of light output from the tubular member will vary with deflection or bending of that member. This property or characteristic enables the flexible member to be used as an optical displacement sensor. For example, one end of the tubular member may be fixed to a reference point and the other end may be connected, either directly or indirectly to the measurand. Any displacement of the end connected to the measurand caused by movement of the measurand can be detected by variation in the output of the light detector. Other fixing arrangements can be used. For example, both ends of the flexible tubular member may be fixed to reference points, and an intermediate portion connected, either directly or indirectly to the measurand. In a further modification, several measurands may be connected to points on the tubular member thereby permitting the sensor to detect movement of one or all of a plurality of measurands.

Multiple sensor tubes may be used in any one displacement sensor. Such tubes can be coupled optically in series by optical fibre.

The light source is typically a light emitting diode which is optically coupled to one end of the flexible member via an optical fibre. Appropriate focusing and coupling means are provided, if required. A coherent light source is not necessarily required.

The light detector is typically an optoelectric device such as a commonly available photodiode or phototransistor which provides an electrical output dependent on the light received. This output can be connected to appropriate electronic circuitry containing filtering, amplification and signal processing circuits. The light detector is preferably coupled to the other end of the flexible member via an optical fibre.

The light source and light detector are typically at opposite ends of the sensor tube. In an alternative embodiment, both the light source and light detector are

located at the same end of a tubular optical fibre which acts as the sensor. In this embodiment, light radiation from the light source passes through the tubular fibre and is reflected back to the detector, i.e. the light passes twice through the sensor tube. The flexible tubular sensor fibre can be mounted in cantilever fashion with one end fixed to a reference point and its free end movable in response to the measurand.

The optical displacement sensor of this invention has several advantages. First, it is simple and inexpensive to construct and install, and does not require complex light transmission or detection equipment. Secondly, as only a small force is required to deflect the flexible sensor tube, the sensor has high sensitivity and can be used to detect small displacements. Thirdly, the simple basis of operation of the sensor results in a high degree of reliability. Fourthly, the sensor has all the advantages of optical fibre instrumentation, such as noise immunity, electrical isolation and ease of miniaturisation.

In order that the invention may be more fully understood and put into practice, preferred embodiments thereof will now be described by way of example only, with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig.1 is a schematic sectional diagram of the optical displacement sensor of this invention, showing various modes by which light may be attenuated by the sensor tube;

Fig.2 is a schematic diagram of a one embodiment of the optical displacement sensor;

Fig.3 is a schematic diagram of a second embodiment;

Fig.4 is a diagram illustrating one application of the sensor of Fig.3; and

Fig.5 is a sample output of the sensor of Fig.4.

DESCRIPTION OF PREFERRED EMBODIMENTS

As shown in the upper portion of Fig.1, the optical displacement sensor 10 of a first embodiment of

this invention comprises a sensor tube 13 joined to a pair of optical fibres 11, 12 at its opposite ends. The optical fibres 11, 12 are typically 1mm diameter polymer optical fibres (with protective sleeves), although the length, size and type of optical fibres may be varied to suit particular applications. The sensor tube 13 is a flexible compliant tube with an internal diameter matching that of the core of each optical fibre 11, 12. In this manner, the cores of optical fibres 11, 12 may be easily coupled to opposite ends of the sensor tube 13.

The sensor tube 13 is reflective on its internal surface and provides only minimal attenuation to the passage of light when not distorted due to internal reflection. The reflective internal surface may be provided either by inherent nature or by specific manufacture, i.e. a metallised coating. Suitable flexible materials for the sensor tube include plastics such as vinyl and rubbers, both natural and synthetic. The outer surface of the tube is typically opaque to shield the sensor from ambient light.

A light source, typically an infrared or visible light emitting diode 14, is optically coupled to the free end of optical fibre 11. An optical detector 15, such as a photodiode or phototransistor, is connected to the free end of optical fibre 12. The output of the detector 15 is connected to an electronic circuit providing the necessary amplification, filtering, and an output display, if required. The output of the detector electronics can also be used to control dependent apparatus.

The length of the sensor tube 13 is typically of the order of 2 to 10cm, but may be varied to suit the particular application of the sensor 10, the intensity of the light source 14, and the sensitivity or gain of any amplification circuitry connected to detector 15.

As can be seen in the lower portions of Fig.1, any deflection or distortion of the flexible sensor tube 13 caused by deforming forces A, B, or difference in pressures p1, p2 outside and within the tube 13, will affect the

transmission of light therethrough, namely by changing the number of internal reflections which the light undergoes. More specifically, if the number of internal reflections is increased as a result of a change in the configuration of the tube 13, the intensity of light transmitted through the tube 13 will be decreased as each reflection is less than 100% efficient. Thus, any deflection of the sensor tube 13 caused by displacement of one portion thereof relative to another will be detected by variation in the amount of light received by optodetector 15.

Variations (if any) in the intensity of light emitted by diode 14 can be avoided by an electronic light intensity referencing circuit connected to the diode, or accommodated by a second parallel optical fibre between diode 14 and light detector 15, acting as a reference beam.

A particular advantage of the optical displacement sensor 10 is the ability to detect small deflections or displacements, while being electrically isolated from the measurand or deflecting member. Further, the pliant sensor 10 is highly sensitive to displacement forces, yet robust in construction.

A modified version of the embodiment of Fig.1 is shown in Fig.2. In the sensor 20 of Fig.2, light from a light source 21 is focused by lens 22 for transmission through a tubular fibre 23. The light is reflected at the distal end of the tube 23, and is detected by an optodetector 25 which typically is a photodiode or phototransistor. Discrimination of the incident light from the reflected light is performed optically as shown in the arrangement of Fig.2. Light from the light source 21 passes twice through the tubular sensor fibre 23 before detection by the optodetector 25. Any distortion 24 of the tubular sensor fibre will attenuate the amount of light received by optodetector 25. Hence, the intensity of light detected by optodetector 25 provides an indication of the deflection or displacement 24 of the free end of tubular sensor fibre 23.

Deflection or displacement of the sensor tube or

fibre may be either direct or indirect. Direct distortion can occur, for example, when the sensor tube is adherent at an intermediate point to the measurand and anchored to two reference points on either side thereof. Further, the sensor tube may be adhered to the measurand at several points, with its ends anchored to reference points. In this manner, complex deflection curves may be sensed. The embodiment of Fig.2 is particularly suitable for this type of application.

Indirect distortion can occur through the transmission of force through a system of levers or other interconnecting components in order to introduce some mechanical gain (or loss) or alter the linearity (or otherwise) of the optical sensing system.

An embodiment of the optical sensor, adapted for the specific purpose of angular displacement sensing, is shown in Fig.3. A light source (not shown) is optically coupled to one end of an optical fibre 31, the other end of which is connected to one end of a flexible sensor tube 32, e.g. in the manner shown in the top portion of Fig.1. The optical fibre 31 (provided with a protective sleeve) is held within a channel in a rigid strip member 36.

The other end of sensor tube 32 is connected to a second optical fibre 33, the other end of which is connected to a second sensor tube 34. The second optical fibre 33 (in its protective sleeve) is held in a U-shaped channel in a second rigid flap member 35. The other end of the second sensor tube 34 is connected to a third optical fibre 37 which is similarly located (in its protective sleeve) within a channel in rigid strip member 36, parallel to optical fibre 31. The distal end of optical fibre 37 is optical coupled to a optodetector device (not shown). The connections between the optical fibres and the sensor tubes are generally as shown in Fig.1.

The sensor tubes 32, 34 form connecting bridges between strip 36 and flap 35. Since the sensor tubes 32, 34 are flexible, they form a hinge-like connection between the flap 35 and strip 36, permitting the flap 35 to pivot

about that hinge connection. As the flap 35 pivots about the hinge connection formed by sensor tubes 32, 34, the tubes are deformed by bending, thereby affecting the passage of light therethrough. The angular displacement of flap 35 is thereby detected by the change of intensity in light received from optical fibre 37.

A specific application of the embodiment of Fig.3 will now be described with reference to Figs.4 and 5. In this application, the optical sensor 30 is used to detect respiratory movements in small animals, e.g. a mouse 41. The optical fibre 31 is optically coupled to a light source (not shown), suitably via a SWEET SPOT™ housing and connector. The light source is typically a 660 nm (red) light emitting diode with an integral lens to permit optical coupling to one end of the optical fibre 31. The end of the fibre 37 is connected to, and optically coupled with a light detector (not shown). The rigid strip 36 is fixed relative to the probe on which the mouse rests, but the flap 35 is pivotable relative to the strip 36. The flap 35 is lightly biased against the abdomen of the mouse.

The optical sensor 30 of Fig.4 derives from the abdomen of the animal 41 a motional signal indicative of the respiratory movement of the animal. Intensity modulation is preferred in distinction to more complex frequency and phase modulation commonly used in (solid) optical fibre sensing. Light in the visible range of the spectrum is preferred due to lower attenuation in the tubular fibre and ease of troubleshooting.

In use, the animal 41 is anaesthetised. The source and detector fibres 31, 37 are then connected to the light source and optodetector, respectively. Light from the source passes through the sensor tubes 32, 34 and into detector fibre 37 where it is detected by the optodetector. The output of the optodetector provides the electrical signal source for further amplification and filtering.

Any localised movement of the animal adjacent the flap 35 due to respiration will cause deflection of the sensor tubes 32, 34. Such deflection or bending is

detected by variation in the intensity of the light detected by the optodetector.

The respiratory movement sensor described above has been trialled on adult Wistar rats and adult Quackenbush mice, and a gatable or trigger signal suitable for use in imaging, for example, has been acquired reliably with both species. Trials in excess of three hours have been performed. The output signal has been displayed on an oscilloscope, after appropriate amplification and filtering. A representative oscilloscope trace is shown in Fig.5. It is to be noted that the output display indicates movements due to inspiration and expiration, hence providing an indication of when the abdominal organs are stationary.

The abovedescribed optical sensor provides a relatively inexpensive and simple means of monitoring respiration of small animals. Other uses or applications of the optical sensor of this invention are described briefly below.

1. <u>Apnoea Alarm</u>

Apnoea, or the cessation of breathing, is a relatively common problem in acute care situations for both children and adults. Paediatric apnoea alarms are used extensively in intensive care units where prematurity or other illness predeposes infants to apnoeic episodes. Known apnoea alarms use instrumentation to monitor respiration in the spontaneously breathing infant by measuring chest wall (e.g. electrical) impedance or by using various forms of a movement responsive blanket placed under the infant. However, both have a relatively high false positive alarm rate.

Home apnoea alarms are prohibitively expensive and, largely for this reason, are generally not used except in cases of infants with a documented history of apnoea or after the death of a sibling

from sudden infant death syndrome (SIDS).

Recovery from a general anaesthetic in which the subject was paralysed requires monitoring post-operatively in case of inadequate of reversal of the paralysis. Currently, this is performed by nursing staff observing the patient. Cases of missed respiratory arrest are not uncommon and the consequences can be dire. The optical sensor of this invention is suitable for use as a respiratory monitor for human patients in a manner analogous to that described above with reference to Fig.4, and can therefore be used as an adjunct to direct observation of respiratory performance of a post-operative patient.

The optical displacement sensor can be used as a "stand alone" unit, or as a component module of more comprehensive monitors used in intensive care units.

2. <u>Respiratory Trigger for Neonates/Infant (MRI)</u>
The optical displacement sensor of this invention can be used as a simple and reliable alternative to known respiratory triggers. The electrical output of the optical sensor is appropriately gated to provide a trigger signal indicative of respiratory movement.

3. <u>Trigger for Radiographic Imaging</u>
In radiography, an image is sometimes required in a specific phase of the respiratory cycle. For example, comparison of inspiratory and expiratory images are essential to accurate diagnosis.

The optical displacement sensor of this invention can be used to monitor both inspiration and expiration phases of the respiratory cycle, and

to provide the appropriate timing signal for imaging. The optical fibre sensor is particularly advantageous when used with nonverbal or preverbal subjects. A similar application is in the field of nuclear medicine where repeated signal acquisitions are averaged to improve image quality.

4. Trigger for Administration of Therapy to Chest or Abdominal Organs

It is standard practice to administer radiation of various modes to predetermined anatomical regions. Examples are the administration of ultrasonic pulses to disrupt impacted kidney stones or administering ionizing radiation to treat tumors. Target tissues will move with respiration and it is possible to trigger the delivery of such radiations with the embodiments of the sensor above described.

5. Monitoring of Gross Body Movement

One or more displacement sensors appropriately placed can indicate the degree of mobility of a subject. Such an implementation may be of use in the study of hyperactivity or movement disorders. The monitoring of rigors or gross shaking due to thermal stress is another application of this sensor.

6. Nocturnal Penile Tumescence (NPT's)

Impotence, or the failure to achieve an erection, is typically first investigated by NPT studies in a sleep study lab. The subject is observed for nocturnal erections usually associated with REM sleep. Failure to produce results delineates organic or physiological disease from a psychological cause.

The optical displacement sensor of this invention, for example the embodiment of Fig.3, can be easily adapted for use in NPT monitoring.

7. Joint Use Studies/Pedometers

Flexion and extension of most joints can be monitored using the optical displacement sensor of this invention. The rate of flexion can be accurately recorded, as well as the angular displacement. (A linearising circuit can be used, if required, for angular displacement studies.) One specific application is a pedometer in which the optical displacement sensor is attached to the knee joint and monitors flexion, and hence steps.

8. Pressure Transducer

The optical displacement sensor of this invention can be used as a pressure transducer by detecting pressure sensitive movement. For example, if the sensor tube is hermetically sealed, the tube will be deformed by a pressure differential between the fluids inside and outside the tube. Such deformation will be detected by the optical sensor. In this manner, the sensor can be used as a pressure transducer. The flexibility of the sensor tube material as well as the internal pressure are chosen to suit the particular application of the pressure transducer.This mode of use is not limited to *in vivo* monitoring but can encompass domestic and industrial applications.

9. Surface Deformation Detector

Deformation of structures or vessels in remote or hazardous environments may be performed with the aforementioned sensor. The sensing tube may be

attached to the structure along its entire length or in a number of points.

Change in the shape of the structure or vessel will cause modulation of light intensity in the sensor and this may be detected in the conventional manner. The sensor therefore acts as a safety device in signalling failure of critical structures and rupture (or pending rupture) of vessels or conduits. Illicit deformation of elements may occur through vandalism or forced entry to premises. Vulnerable portals may be implemented with such a sensor to detect displacement of component elements. The sensor may be concealed in a compliant material thus forming a pressure sensitive mat. Such a device will produce an optical signal similar to that described above.

10. Movement Detector

The optical displacement sensor of this invention has widespread use as a movement detector. Any displacement or deformation of the sensor tube as a result of movements as small as 1mm (or even less) can be reliably detected. The optical displacement sensor therefore finds general application as a limit switch, movement detector for burglar alarms, position feedback indicator in closed loop control systems, etc.

The foregoing describes only some embodiments and applications of this invention, and modifications which are obvious to those skilled in the art may be made thereto without departing from the scope of the invention. For example, the output of the optodetector would normally be fed to an electrical circuit for filtering, amplification and/or level discrimination. Alternatively, the detector output may be fed to a microprocessor-based circuit to provide automatic gain and level triggering, as well as

software-based self diagnostic facilities. Further the degree of reflectivity of the internal surface of the sensor tube may be varied to vary the sensor's characteristics and performance.

CLAIMS:

1. An optical displacement sensor comprising an elongate flexible optical element suitable for the passage of light axially therethrough, the optical element being deformable by displacement of a first portion thereof relative to another portion; a light source optically coupled to one end of the optical element for transmitting light radiation into the optical element; and a light detector for detecting the light radiation after passage through the optical element, the light detector providing an output indicative of the intensity of light detected, wherein the detector output is responsive to variation in the intensity of light transmitted through the optical element as a result of deformation thereof,

characterised in that the optical element is a tubular member.

2. A sensor as claimed in claim 1, wherein the tubular member is a hollow tube of plastics material.

3. A sensor as claimed in claim 2, wherein the hollow tube has a reflective internal surface.

4. A sensor as claimed in claim 3, wherein the internal surface has a mirrored finish.

5. A sensor as claimed in claim 2, wherein the hollow tube has an opaque outer surface.

6. A sensor as claimed in claim 1, further comprising a first solid optical fibre having one end optically coupled to the light source and its other end received within one end of the tubular member; and a second solid optical fibre having one end received within the other end of the tubular member and its other end being optically coupled to the light detector.

7. A sensor as claimed in claim 6, wherein the light source is a light emitting diode, and the light detector is an optoelectric device.

8. A sensor as claimed in claim 1, wherein the optical element comprises a plurality of tubular members optically coupled in series.

9. An optical sensor as claimed in claim 1, wherein

the light source and the light detector are located at the same end of the optical element, the light passing through the optical element being reflected from one end thereof back to the light detector.

10. A device for measuring small displacements of an object, comprising an optical element and means for detecting the intensity of light transmitted through the optical element, the optical element being connected, directly or indirectly, to the object such that displacement of the object deforms the optical element, such deformation being detected by variation in the intensity of light transmitted through the optical element, characterised in that the optical element is a flexible tubular member.

11. A device for measuring pressure changes, comprising an optical element and means for detecting the intensity of light transmitted through the optical element, the optical element being subjected, in use, to said pressure such that variation in the pressure deforms the optical element, such deformation being detected by variation in the light transmitted through the optical element, characterised in that the optical element is a sealed flexible tubular member.

AMENDED CLAIMS

[received by the Internationl Bureau on 30 August 1993 (30.08.93); original claims 1-11 replaced by amended claims 1-11 (2 pages)]

1. Apparatus for monitoring surface movement, comprising a member having at least two juxtaposed parts, at least one part being adapted to be placed against the surface so as to move in response to movement thereof,

an optical tube located at the junction of the two parts such that the configuration of the tube is changed by relative movement between the two parts,

a first solid optical fibre having one end connected to one end of the optical tube and its other end optically coupled to a light source such that light from the source is transmitted to the tube,

a second optical fibre having one end connected to the other end of the optical tube and its other end optically coupled to a light detector such that light passing through the tube is transmitted to the light detector, the output of the light detector being responsive to variation in the intensity of the light transmitted through the tube as a result of changes in the configuration thereof.

2. Apparatus as claimed in claim 1, wherein the surface is the skin of an animal and said movement is caused by involuntarily muscle movement of the animal.

3. Apparatus as claimed in claim 2, wherein the two parts are of planar form and are hingedly connected.

4. Apparatus as claimed in claim 3, wherein the apparatus is adapted for use with an NMR probe, one part being placed in contact with the skin and the other part being fixed relative to the probe.

5. Apparatus as claimed in claim 4, wherein the optical tube comprises at least two tube components connected by a solid optical fibre.

6. Apparatus as claimed in claim 3, wherein the light source is a light emitting diode, the light detector is an optoelectric device, and the tube is made of flexible plastics material.

7. Apparatus for monitoring involuntary muscle movement, comprising

a first, generally planar, component adapted to be placed adjacent the muscle so as to move in response to movement of the muscle,

a second component adjacent the first component,

a pair of optical tubes each connected between the first and second components,

a first solid optical fibre connected between a respective end of each tube on the first component,

a second optical fibre having one end connected to the other end of one tube, and its other end optically coupled to a light source,

a third solid optical fibre having one end connected to the other end of the other tube, and its other end optically coupled to a light detector,

wherein light from the light source passes through both tubes to the detector, and the detector output is responsive to variation in the intensity of light transmitted through the optical tubes as a result of deformation thereof by relative movement between the first and second components.

8. Apparatus as claimed in claim 7, wherein the apparatus forms part of a NMR probe, and the second component is fixed relative to the probe.

9. Apparatus as claimed in claim 7, wherein the optical tubes, and the first, second and third optical fibres are at least partially located in channels formed in the first and second components.

10. Apparatus as claimed in claim 7, wherein the first and second components are hingedly connected.

11. Apparatus as claimed in claim 7, wherein the tubes are of angled configuration when the first and second components are coplanar.

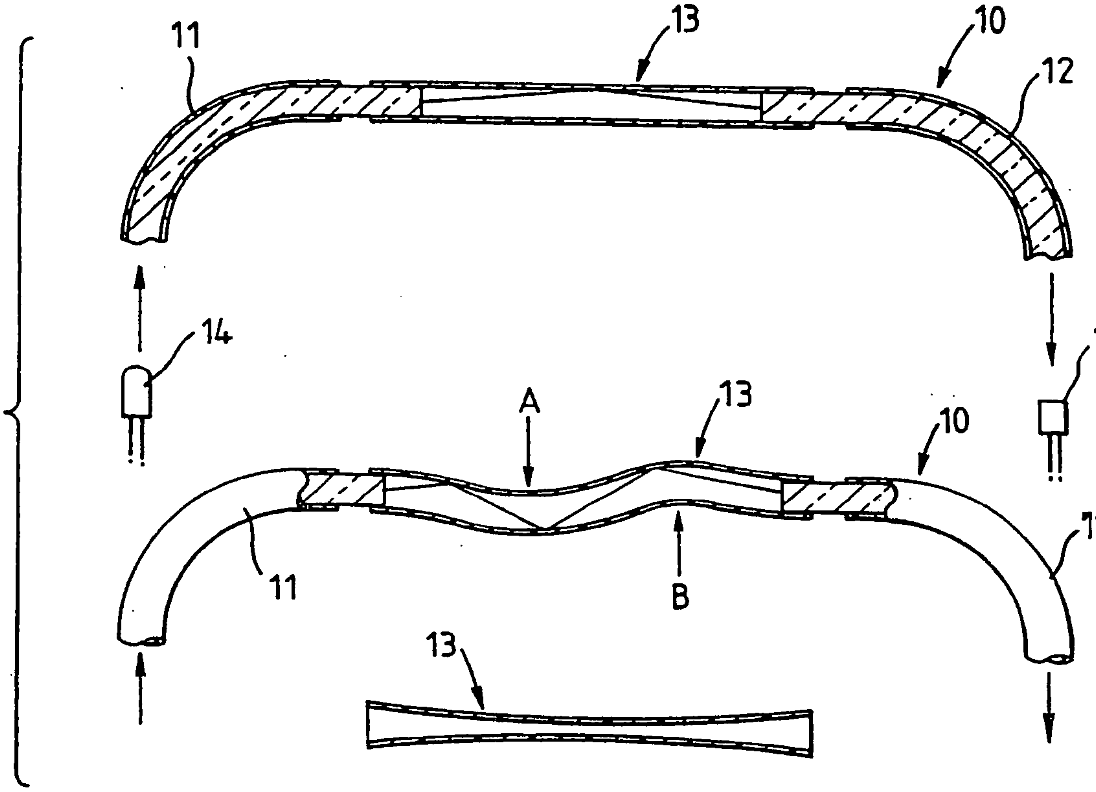


Fig.1.

Fig.2.

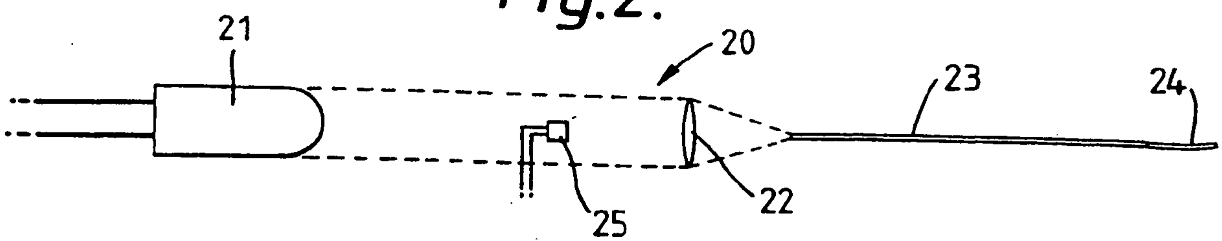
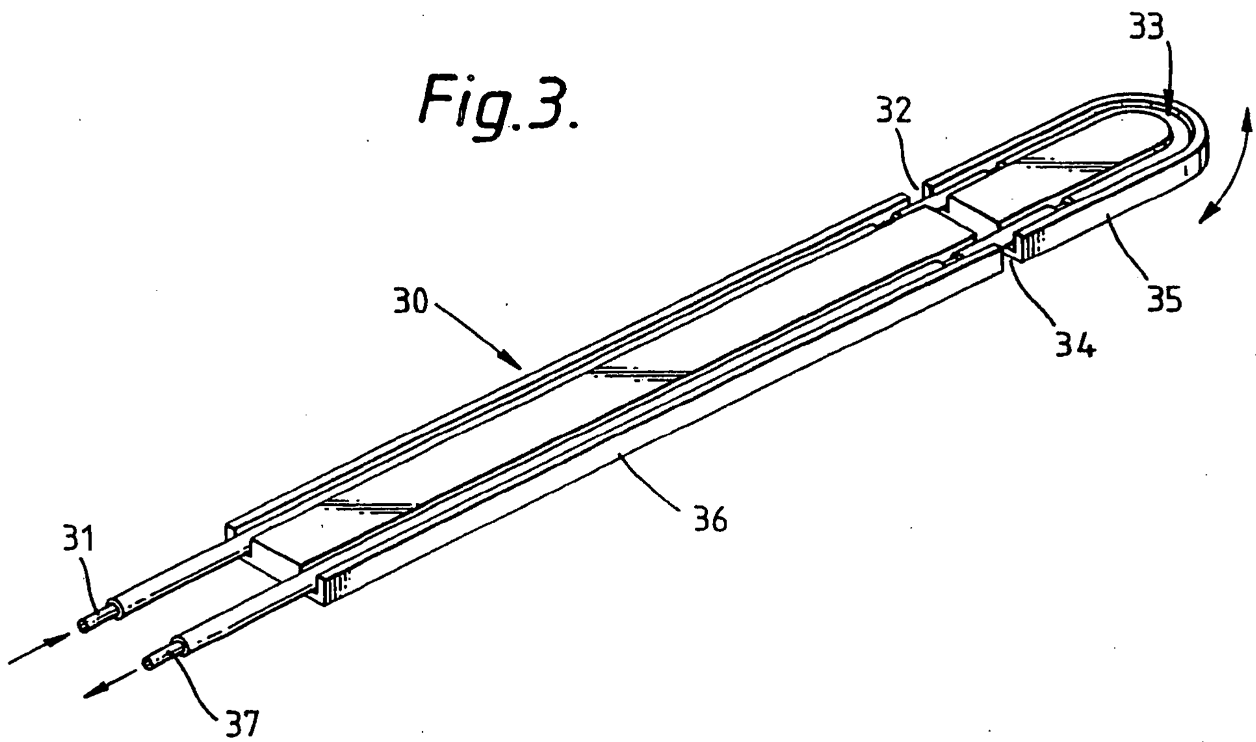


Fig.3.



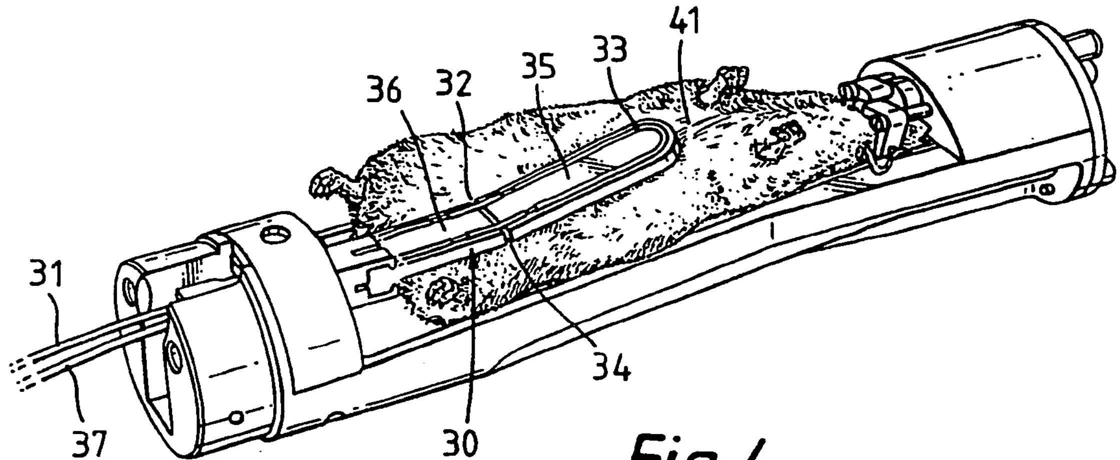


Fig.4.

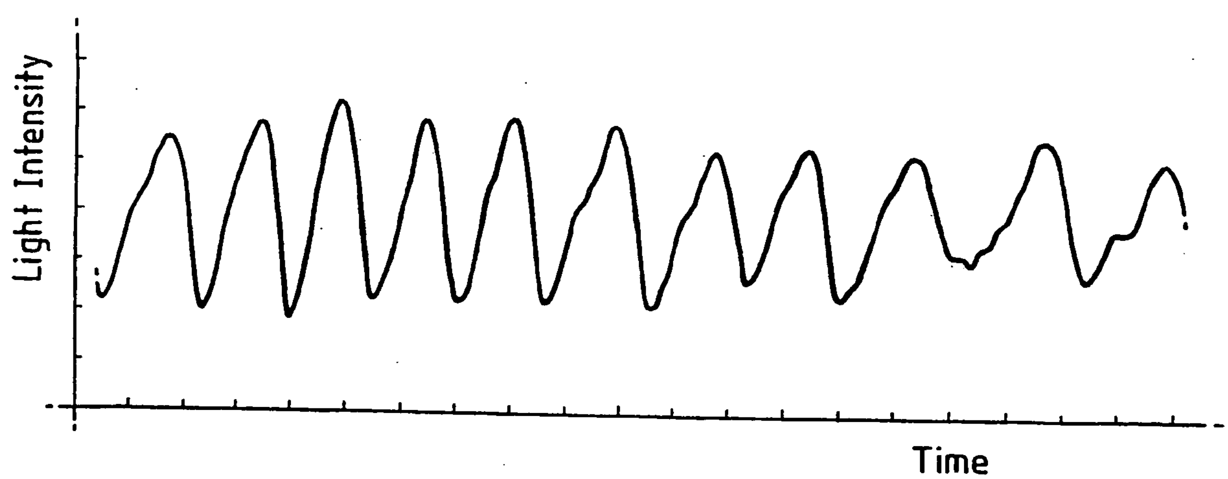


Fig.5.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU93/00202

A. CLASSIFICATION OF SUBJECT MATTER
Int. Cl.^{5} G01D 5/34, G01B 11/16, G01L 7/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC G01D 5/34, G01B 11/16, G01L 7/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU : IPC as above as well as G01B 11/00, 11/02, 11/18, G01L 7/00, 7/02, 11/00

Electronic data base consulted during the international search (name of data base, and where practicable, search terms used)
DERWENT : tub: and light and (G01L/IC or G01B/IC or G02B/IC) and (displace: or pressure or motion) and flexib:

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
X	DE,A, 3334395 (FRAUNHOFER-GES FORD ANGE) 11 April 1985 (11.04.85) figures 1 to 4	1-11
X	DE,A, 3236435 (FRAUNHOFER-GES FORD ANGE) 5 April 1984 (05.04.84) pages 3 to 5 and figure 1	1-8,10,11
X	FR,A, 2578974 (LACH) 19 September 1986 (19.09.86) figures 1 to 8	1,2,5,9-11
X	US,A, 5097252 (HARVILL et al) 17 March 1992 (17.03.92) column 5 lines 13 to 52 and figures 11 to 14	1-5,10,11

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 June 1993 (15.06.93)	18 JUNE 1993 (18.06.93)

Name and mailing address of the ISA/AU	Authorized officer
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C(Continuation).	DOCUMENTS CONSIDERED TO BE RELEVANT	
Category*	Citation of document, with indication, where appropriate of the relevant passages	Relevant to Claim No.
X	US,A, 4937444 (ZIMMERMAN) 26 June 1990 (26.06.90) column 2 line 1 to column 3 line 25 and figures 1 to 3	1-7,10,11
X	US,A, 4542291 (ZIMMERMAN) 17 September 1985 (17.09.85) column 1 line 59 to column 3 line 18 and figures 1 to 3	1-7,10,11
X	US,A, 4414537 (GRIMES) 8 November 1983 (08.11.83) column 3 line 56 to column 4 line 19 and figures 4 and 5	1,2,5,10,11
X	Patent Abstracts of Japan, P-1169, page 161, JP,A, 2-296110 (OSUTO KK) 6 December 1990 (06.12.90) abstract	1-5,10,11

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member			
US	5097252	EP	352291	WO	8807659
					END OF ANNEX